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Testing of Mylar Tear-Off Windshield Film for Aircraft

Nathaniel E. Bordick and Mark E. Robeson

Aviation Applied Technology Directorate
AMSRD-AMR-AA-F
Fort Eustis, VA 23604-5577

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Abstract

In an effort to combat windscreen erosion on Army aircraft, a Mylar film has been developed to apply directly to the environmentally exposed surface of windscreens. This film can be applied to aircraft windscreens in single or multiple layer sheets, which once removed will leave no permanent residue on the underlying surface. A qualitative evaluation of Mylar Tear-Off Windshield Film (MTOWF) has been conducted, and indicates that MTOWF is appropriate for Army aircraft application. For example, the testing showed that the installation, cleaning, and removal of MTOWF are quick and easy. In addition, the optical qualities of MTOWF and its resistance to damage and delamination are sufficient for Army aircraft use. Finally, testing showed that MTOWF does not hinder night vision goggle performance and that any electrostatic build-up issues can be overcome. MTOWF protects the windscreen, prolonging its operating life and ultimately increasing aircraft readiness. By protecting the windscreen, MTOWF will save the Government Operations and Support (O&S) costs, since it is much cheaper and quicker to replace MTOWF than to replace a windscreen.

Keywords: windscreen, windshield, Mylar, film, erosion protection

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1. INTRODUCTION

The windscreens of Army aircraft are adversely affected by erosion. In an effort to combat windscreen erosion, United Protective Technologies (UPT) developed a Mylar film that is applied directly to the environmentally exposed surface of windscreens. Though introduced in 1997 for use in National Association for Stock Car Auto Racing (NASCAR), the implications for Army aircraft are clear. Mylar Tear-Off Windshield Film (MTOWF) is designed to resist damage from particulate impacts, which may otherwise harm an unprotected windscreen. This film is applied to aircraft windscreens in a single sheet, which once properly removed will leave no residue on the underlying surface nor impair the transparency qualities of the windscreen. The film can be pre-formed to fit most windscreen designs. Application methods are simple, and windscreen life could potentially become infinite by applying a new MTOWF to the windscreen on a regular basis.

The U.S. Army Research, Development and Engineering Command's Aviation Applied Technology Directorate (AATD) has conducted a qualitative evaluation of MTOWF for the Aviation and Missile Research, Development, and Engineering Center (AMRDEC) Reliability and Maintainability (RAM) Engineering Division and the Defense Logistics Agency (DLA). Prior to this, MTOWF had not been evaluated in an aerospace environment. This test program was intended to provide critical information to DLA, UH-60 Program Management Office (PMO), CH-47 PMO, the Army's Aviation Engineering Directorate (AED), and the user community, in order to aid in determining the performance and potential mission impacts of the MTOWF.

2. OBJECTIVES

The objective of the MTOWF test program was to use initial risk mitigation building block testing and AATD's ground and flight testing to determine if MTOWF is appropriate for use on Army aircraft. In order to determine this, several areas were addressed. The installation, removal, and cleaning procedures were evaluated, as were the optical qualities of MTOWF. In addition, the resistance of MTOWF to damage and delamination, due to aircraft systems and operational environments, was thoroughly evaluated. Finally, testing was conducted to determine if MTOWF had any impact on aided or unaided night vision, de-icing, or communications.

3. TEST PROGRAM AND RESULTS

For the purposes of this test program, a single Mylar Tear-Off Windshield Film sheet 0.007-inches (7-mils) thick was evaluated. UPT provided AATD material and adhesion properties of the MTOWF, which are summarized in Table 1. The MTOWF is expected to have an average installed life of 6 months, based on anticipated degradation due to the effects of ultraviolet light. UV degradation has not been characterized.

Table 1. MTOWF (0.007" thick) properties.

Tensile Strength	27,614 psi, Transverse Direction (TD)
	23,000 psi, Machined Direction (MD)
% Elongation	150%, TD
	200%, MD
Break Strength	190 lbs., TD
	160 lbs., MD
Puncture Strength	121 lbs. force
Haze	0.50%, per ASTM D1003
Light Transmission	92.5%, per ASTM D1003
Scratch Resistance	Change in Haze 9.0%, per ASTM D1044
Maximum Estimated Life	6 months
Dielectric Strength	13.5 kV, per ASTM F1249
Surface Resistivity	1 E12 to 1 E13 Ohms/sq in.
Adhesion Strength to Glass	3,200 grams/in. width

Three aircraft were used in the MTOWF testing, a C-12 fixed wing aircraft, a UH-60 helicopter, and a CH-47 helicopter, as shown in Figure 1. The C-12 test aircraft was a production C-12C fixed wing aircraft as described in Ref. 1, with MTOWF installed on the right side glass windscreen. The UH-60 test aircraft was a production UH-60A helicopter, as described in Ref. 2, with MTOWF installed on the left segment of the windscreen. The CH-47 test aircraft was a production CH-47D helicopter as described in Ref. 3, with MTOWF installed on the left segment of the windshield. In all cases, MTOWF was applied to the outward windscreen surface following manufacturer's instructions. For the UH-60, the manufacturer supplied pre-formed and pre-cut MTOWF to ensure the whole windscreen panel was covered, while for the C-12 and CH-47, the MTOWF was cut to size at the time of installation to ensure that the whole windscreen panel was covered.

Figure 1. Test aircraft with test windscreens circled.

The C-12 was chosen for preliminary flight testing because it enabled a variety of airspeeds, temperatures, and weather conditions to be tested in a short time. Once the test results were gathered for the C-12, testing began with the UH-60 and CH-47, starting with initial ground tests and then proceeding to flight tests. This approach reduced the risk of any unforeseen problems prior to durability testing at the Army's Yuma Proving Grounds (YPG). As a safety precaution, MTOWF was only installed on one of each aircraft's windscreens. In addition, MTOWF was examined before, during, and after each ground and flight test to determine if there was any degradation in clarity or adhesion. A survey was completed after each test flight by the test pilots to evaluate the clarity and performance of MTOWF.

Areas addressed by the test program were as follows: installation/removal/cleaning, resistance to damage/delamination, optical quality, night vision goggle (NVG) compatibility, and electrostatic build-up.

3.1. Installation/Removal/Cleaning

The manufacturer provided an installation kit containing all of the necessary instructions, tools, chemicals, and MTOWF required to complete a full installation. The installation solution was provided in pre-measured packets that only required mixing. This solution is a non-hazardous detergent and water mixture used to clean the windscreen surface and activate the film's adhesive.

The MTOWF installation procedure was demonstrated to be straightforward, with the key steps illustrated in Figure 2. First, the windscreen was thoroughly cleaned using the film application solution. Next, the MTOWF was cut to size and molded to the correct curvature of the windscreen. The backing was then removed from the MTOWF, and both the MTOWF and windscreen were heavily sprayed with the film application solution. The MTOWF was then placed on the windscreen and squeegeed into place, making sure to push out all of the air pockets. Finally, the MTOWF adhesive was allowed to cure for 24 hours.

Figure 2. MTOWF trimming to shape, heat forming, and squeegeeing to windscreen.

The manufacturer's recommended MTOWF installation procedure has been successfully demonstrated in a hanger numerous times on the CH-47D and UH-60A rotorcraft, as well as on a C-12C aircraft. One CH-47 installation at AATD, the only unsheltered installation, was unacceptable due to bubbles under the MTOWF, as shown in Figure 3, but a subsequent re-installation was satisfactory.

Figure 3. Bubble on windscreen due to contaminated installation.

The installation procedure was evaluated for ease of use and field practicality. On the whole, the MTOWF installation was not difficult, provided the necessary tools were available. Based on the installation experience, it is recommended that all installations occur in an environment sheltered from wind and dust.

The MTOWF removal procedure is simple, and if performed correctly does not leave any adhesive residue on the windscreen. The MTOWF is cut into about 6" to 8" strips by using a razor blade (supplied in the installation kit), which does not damage a glass windscreen. Only minimum pressure is required to slice through the MTOWF. Next, a corner is lifted up, using a razor blade edge, so that the film can be grasped and slowly pulled away from the windscreen. It is important that each strip is pulled slowly and steadily to eliminate tearing of the MTOWF and to avoid leaving any adhesive residue on the underlying windscreen. Once all strips are removed, the windscreen is cleaned using a standard window cleaner. If there is any adhesive residue remaining on the windscreen, it is removed by applying an oil/grease removal chemical and scraped off with a razor blade or plastic scrubbing pad (all are included in the installation kit). The MTOWF removal was demonstrated to be a simple procedure, and took only about 5 minutes per windscreen when the procedure was followed correctly. Deviations from the recommended removal procedure, which lead to tearing of the film and increased residue on the underlying windscreen, drastically increased the removal time.

The MTOWF cleaning procedure is no different than the standard procedure for cleaning a bare windscreen. It was demonstrated that the MTOWF was not harmed by common window cleaning chemicals. The MTOWF was soaked in window cleaning solution for 5 days without any noticeable degradation in adhesion or clarity. In addition, it was observed that MTOWF was much easier to clean than a bare windscreen. Marks that would typically require scrubbing only needed to be wiped or sprayed off of the film. The cleaning process was determined to be quick, easy, and effective.

3.2. Resistance to Damage/Delamination

The MTOWF's ability to resist damage as well as stay adhered to the aircraft's windshield was evaluated. MTOWF was able to resist damage during temperature and sandblast tests, wet and dry wiper usage, de-icing system operation, as well as numerous flight hours in a wide variety of flight conditions.

In NASCAR applications, MTOWF is adhered to a hard coated acrylic windscreen, which is very similar to an aircraft windscreen, by an adhesive with a strength of 180 grams/inch, which has proven satisfactory for speeds approaching 200 mph. A mixture of mild detergent and water is used to help prepare the windscreen surface. This chemical cleans the windscreen surface and activates the adhesive. Once in place and activated, MTOWF is attached to the windscreen surface with an adhesive. It is assumed that the stronger adhesive (3,200 grams/in) used in aircraft applications provides better adhesion, however, no effort was made to establish the airspeed limits.

Redstone Technical Test Center (RTTC) performed testing on windscreen panels, with MTOWF installed, to evaluate high temperatures and solar radiation initial effects on the film and adhesive. The first test was done by cycling temperatures between 90°F and 150°F for seven days, in accordance with (IAW) MIL-STD-810F, Method 501.4-8, Table 501.4-II. The second test was a solar radiation test in which three cycles of solar heating were applied to the specimen IAW MIL-STD-810F, Method 505.4, Procedure I, Temperature Category A1. There was no peeling, bubbling, discoloration, or other anomaly in either test. RTTC also performed a sandblasting test to compare a MTOWF equipped windscreen to a bare windscreen. The results showed that the windscreen with MTOWF attached could last approximately twice as long as the windscreen alone before maintenance was required. It should be noted that the maintenance action required for the MTOWF equipped windscreen was film replacement, whereas the bare windscreen required complete windscreen replacement.

The windscreen must not be scratched or damaged by the operation of dry windshield wipers as stipulated in Reference 4. The MTOWF on the C-12, UH-60, and CH-47 aircraft was tested on the ground and during flight to ensure that this requirement was satisfied. This testing was repeated with moist windscreen/wiper conditions, as shown in Figure 4. All wiper testing demonstrated that the MTOWF was unaffected. In addition to the wipers, the windscreen de-icing mechanisms of the C-12, UH-60, and CH-47 were tested for compatibility with MTOWF (see Figure 5). The de-icing mechanism's ability to heat the windscreen was evaluated. Thermocouples were attached to the outer surfaces of the MTOWF-treated and bare windscreen sections. The de-icing mechanism was then activated and allowed to heat up to its maximum temperature, per the operator's manual. No temperature differences were noted between the windscreen sections, leading to the conclusion that MTOWF does not affect the de-icing function. On the ground and during numerous flights, the de-icer was allowed to function and maintain its full temperature. No loss of adhesion, bubbles, discoloration, or other anomalies were noted. These results indicate that MTOWF is compatible with the de-icing mechanisms of the C-12, UH-60, and CH-47.

Figure 4. Moist wiper test.

Figure 5. De-icing temperature comparison test.

The ability of MTOWF to remain clear and adhered to the windscreen was evaluated for various altitudes, airspeeds, temperatures, and simulated rain conditions. The altitude ranges evaluated were from sea level to 25,000 ft, and no altitude effects were noted. Tested airspeeds ranged from 0 to 310 knots, and no airspeed effects were noted. The windscreen operating temperature range, as specified in Reference 4, is from –65°F to 160°F. High temperature performance was evaluated under the building block testing; therefore, it was AATD's responsibility to evaluate the lower operating range. A preliminary test was performed in which a MTOWF/glass sample was cold temperature cycled numerous times from –15°F to 70°F to check for any shrinkage, peeling, discoloration, bubbling, or hazing in the MTOWF. No temperature effects were noted. Flight testing occurred in a temperature range of –31°F to 95°F, and no temperature effects were noted. A follow on temperature evaluation (see Figures 6 and 7) occurred in an environmental chamber, where a windshield with the MTOWF installed was cycled between -70°F and 170°F, with similar results. Rain conditions were simulated at Fort Eustis, since none of the test flights occurred during a rainstorm. For example, the UH-60's windscreen was sprayed by a hose while the aircraft was on the ground with rotors turning. Also, during a CH-47 test flight, the pilot hovered approximately one foot above the James River to kick-up spray. Under both of the simulated rain conditions, no negative rain effects were noted. According to pilot feedback, the windscreen equipped with MTOWF allowed for more effective rain removal from the wipers, compared to the bare windscreen. The environmental condition testing showed that the integrity of MTOWF was not affected by the investigated altitudes, airspeeds, temperatures, and simulated rain conditions, with the MTOWF remaining clear and attached under each tested condition.

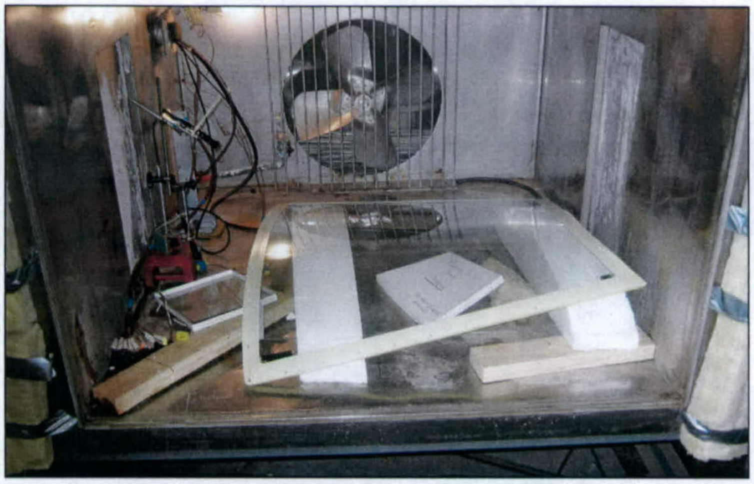

Figure 6. Environmental temperature test.

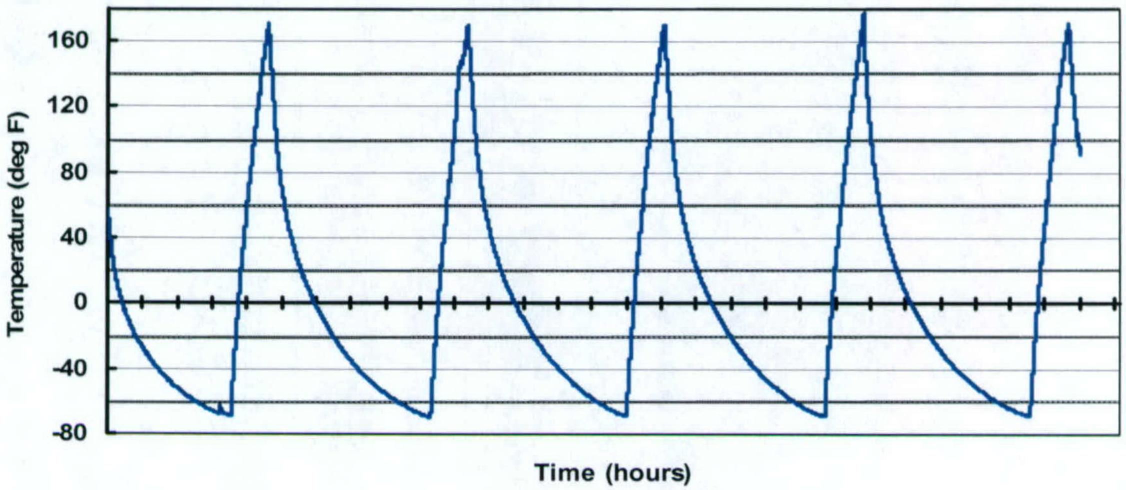

Figure 7. Temperature evaluation of the MTOWF.

In addition to more than 100 hours of flight testing by AATD, the durability of MTOWF was also evaluated during the brown-out condition testing at Yuma Proving Grounds (YPG). Two aircraft, UH-60 and CH-47, were subjected to brown-out conditions during landings and take-offs, blasting the windscreens with dust and rocks, as shown in Figure 8. In the course of seven days of testing, each aircraft logged over fifty take-offs and landings. After each test day the windscreens were examined and a comparison was made between the treated and untreated windscreens. Also, the test pilots completed pilot surveys, evaluating the performance of the MTOWF. Throughout the brown-out condition testing, the untreated windscreens began to pit and show damage, as shown in Figure 9. The MTOWF treated windscreen was a different story. Even though the film began to show signs of wear, the underlying windscreen was protected and remained unaffected by the elements. The surveys indicated that MTOWF was not a distraction to the pilots. Additionally, the maintenance personnel expressed how easy it was to clean and maintain the MTOWF covered windscreen. These results indicate that the MTOWF covered windscreen is at least as durable as the glass windscreen, with the added benefit that once the MTOWF becomes worn, it can be removed, revealing a clear and undamaged windscreen.

Figure 8. Brown-out durability testing for UH-60 (left) and CH-47 (right).

Figure 9. Pitting on unprotected windscreen (left) and no damage on protected windscreen upon removal of the MTOWF (right).

3.3. Optical Quality

The optical properties of MTOWF, as shown in Table 1, were acceptable per Reference 4. The specification states that a new UH-60 transparency must have light transmission greater than 70% and haze less than 2%. The Night Vision and Electronic Sensors Directorate (NVESD) tested a flat windscreen with MTOWF varying in number of layers and thickness in order to evaluate the spectral transmission capabilities and limitations of MTOWF. The results showed that the spectral transmission exceeded what was reported for the UH-60 windscreen over both photopic waveband (400-700 nm) and the effective Aviator Night Vision Image System (ANVIS) waveband (600-900nm).

The optical clarity of the MTOWF was further evaluated by AATD in several ways to ensure that every aspect was addressed. An initial test was performed using a 24" x 34" eye chart, as depicted in Figure 10. The chart was moved toward the front of the aircraft until a line of letters could be clearly read by the observer seated in the pilot's seat. The distance between the chart and windscreen was measured and recorded. The process was repeated for 3 different lines. This test was run on treated and bare windscreen sections on each of the C-12, UH-60, and CH-47 aircraft. The results of the eye chart test, presented in Table 2, showed that there was no noticeable degradation between treated and bare windscreen sections. A second test to determine if any distortion was introduced by MTOWF was performed by moving the eye chart around the front and side of the aircraft. Results showed that there was no distortion detected for any of the three tested aircraft. A third optical characterization was performed using feedback from the pilots flying the aircraft. After each test flight the pilots were tasked to complete a pilot survey, asking questions regarding the clarity of the MTOWF. The results showed all positive feedback except one CH-47 flight, where the previously mentioned poor installation of the MTOWF lead to numerous milky white bubbles and defects in the windscreen cover. The bubbles obscured the pilot's vision and caused minor imagery distortion around the area of the defect. On a different survey, a crew chief noted that the image, as viewed through the MTOWF, could have a wavy appearance at extreme, off-normal viewing angles from non-crew locations within the aircraft. It was determined that the waviness was caused by the adhesive application to the film. The manufacturer has since corrected the issue during production of the film. This testing indicates that the introduction of MTOWF does not affect the windscreens' optical clarity from piloting viewing locations within the aircraft, if installed properly.

Figure 10. Eye chart evaluation.

Table 2. Optical clarity results using eye chart.

Aircraft	Line (Letter Size)	Distance through Windscreen	Distance through Windscreen & MTOWF
C-12	4 (1.375"H x 1.375"W x .375" Thick)	101'	101'
	5 (1.125"H x 1.125"W x .25" Thick)	88' 9"	88' 8"
	6 (.75"H x .75"W x .1875" Thick)	70' 8"	70' 10'
UH-60	4	101' 2"	101' 2"
	5	88' 10"	88' 11"
	6	70' 9"	70' 9"
CH-47	4	101' 1"	101'
	5	88' 7"	88' 7"
	6	70' 6"	70' 7"

3.4. Night Vision Goggle Compatibility

The imaging and resolution for night vision goggles (NVG) was evaluated by NVESD for both flat and curved windscreens treated with MTOWF. There were two tests conducted, as follows:

(1) Measurement of the spectral transmission of the windscreen with and without MTOWF in the 400nm to 1000nm spectral band, which encompasses the spectral responding band of the NVG

(2) Measurement of the maximum discernable resolution with a NVG viewing a 3-bar resolution target with and without the windscreen in its viewing path

The test results showed that the loss in spectral transmission due to the single layer of MTOWF is negligible, as is any loss in resolution incurred by the MTOWF. Based upon these findings, NVESD concluded that the single layer MTOWF is acceptable while using NVGs for nighttime pilotage.

The lab testing at NVESD was followed by flight testing by AATD to ensure that there were no MTOWF/NVG compatibility issues. AATD test pilots flew using NVGs to ensure that the MTOWF did not affect their vision. Test environments were varied, including haze, clear desert (YPG), dark rural areas, and well-lit urban areas. Testing was also performed in a manner similar to the previous optical clarity eye chart test. The test pilots and test engineer were all able to read line 6 from a maximum distance of 29' through the windscreen with and without the MTOWF applied. This testing indicates that MTOWF does not present any NVG compatibility issues.

3.5. Electrostatic Build-Up

Electrostatic build-up ground testing was performed by Naval Air Systems Command (NAVAIR) at the AATD hanger at Ft. Eustis, VA. The testing (see Figure 11) determined the electrostatic characteristics of the MTOWF, and if there would be any Precipitation-Static (P-Static) noise generated by MTOWF-related static electricity build-up and discharge. The characteristics were compared against the windscreen without the MTOWF to determine if charge bleed-off rates were affected. The results showed that the MTOWF acted as a capacitor, storing up charge until the built-up charge would arc to the nearest conductive material. The untreated windscreen completely dissipated the applied 35 kV charge in less than five minutes, whereas the very insulative MTOWF effectively held a charge greater than 8 kV for more than five minutes, as seen in Figure 12. The MTOWF was also observed to retain an 8 kV charge for over 30 minutes. The MTOWF held the charge until enough voltage was built-up to arc through the MTOWF to the windscreen. There was no visible arcing; however, burns up to ½ inch in diameter were evident in the MTOWF. There were 5 to 10 noticeable burn holes generated on each MTOWF after one full charging test. Samples of the burn holes can be seen in Figure 13. A magnification analysis determined that locations of the holes were driven by underlying contaminants, acquired during installation. The testing also showed that the installation of MTOWF resulted in no signs of P-Static noise.

Figure 11. Surface resistivity measurement and charge induction.

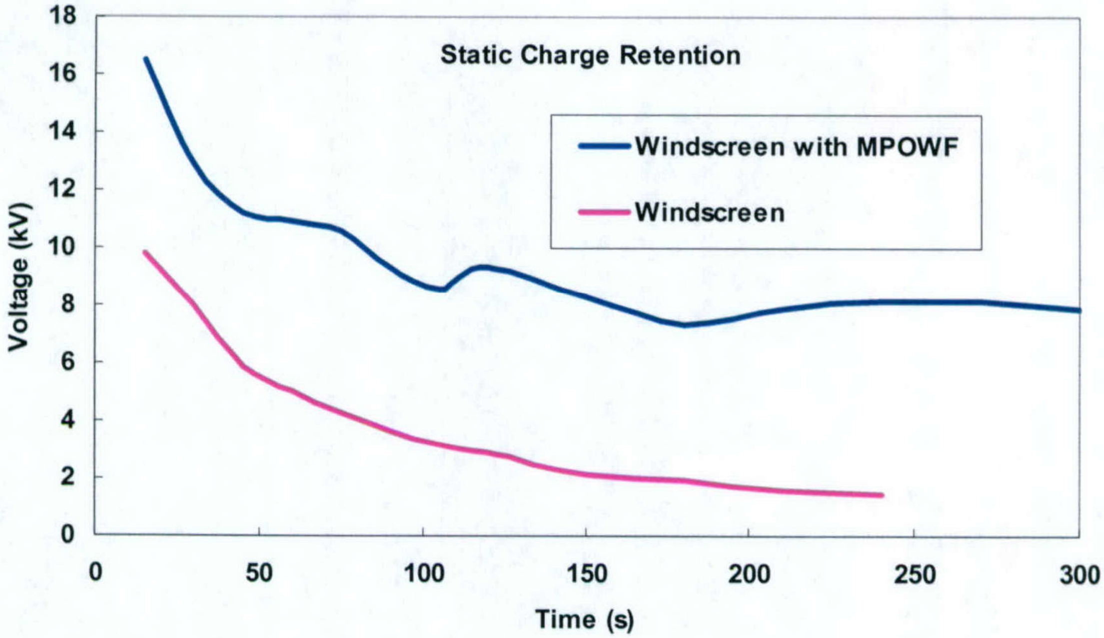

Figure 12. Static charge retention of MTOWF.

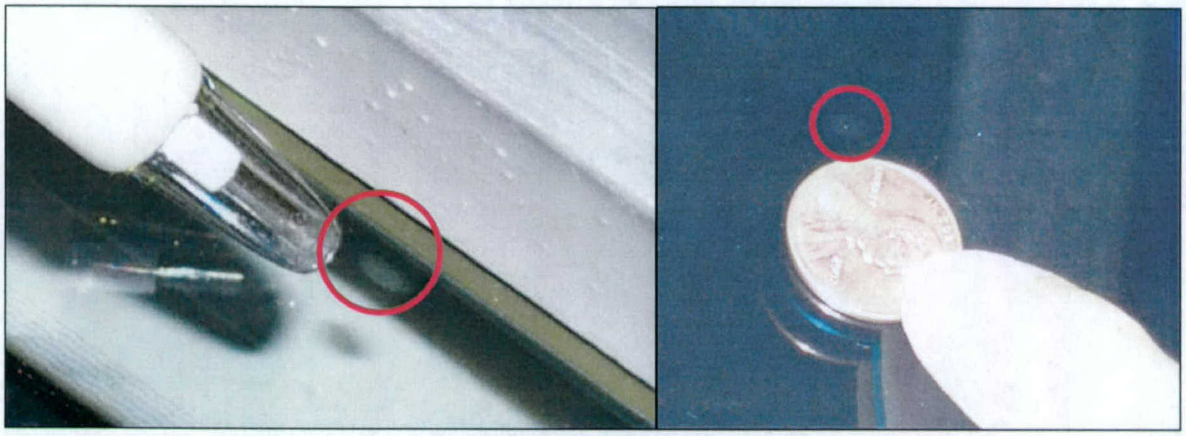

Figure 13. The burn holes in the MTOWF are circled in red.

It was determined that the static charge built up during flight could be eliminated upon landing by either wiping the windscreen with an anti-static glove or misting the MTOWF with water. Flight-testing continued using this practice, however there was no static charge evident on any of the flights. Flight environments included warm and humid at low altitudes, cold and dry at high altitudes, and hot and dry at a variety of altitudes. It was concluded that the 35kV static charge induced during hanger testing is an achievable condition, but is rare in normal flight operation.

After the electrostatic testing, the manufacturer developed an approach to eliminate static build-up. Two MTOWF samples containing a conductive oxide layer just below the hardened outer surface were constructed. The first had a painted layer and the second had only a fine-sprayed layer. The manufacturer installed the two conductive samples as well as a non-conductive sample on a UH-60 windscreen. AATD and NAVAIR repeated the electrostatic build-up test on the samples. Test results of the two conductive samples indicated that the induced static charge was drained at a rate comparable to the untreated windscreen, as seen in Figure 14. This conductive film was not further evaluated in full application or flight testing.

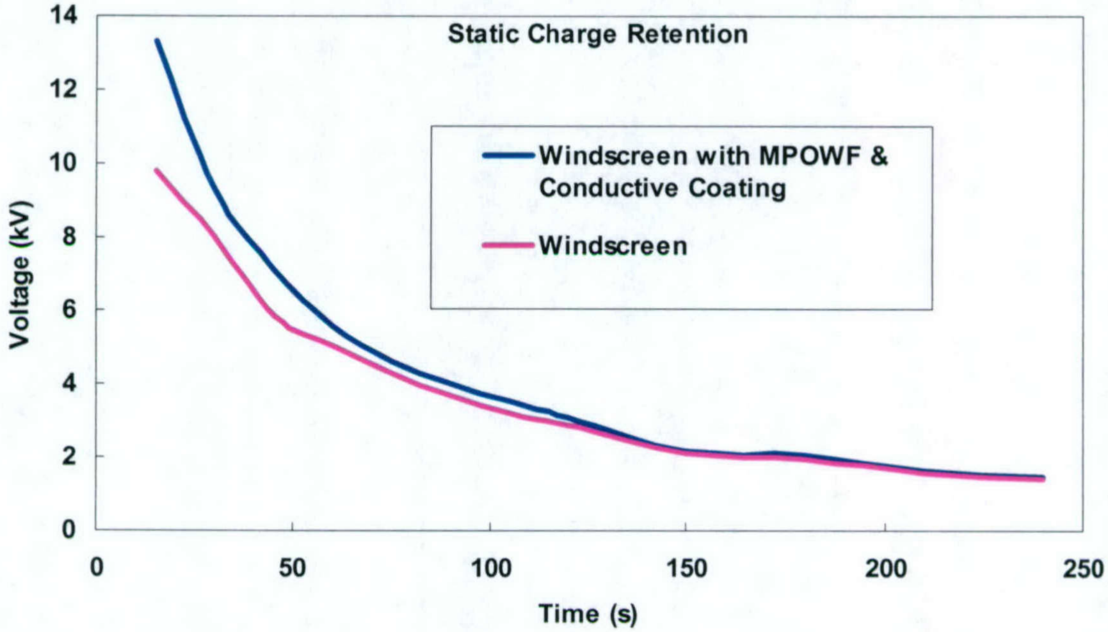

Figure 14. Static charge retention of MTOWF with conductive coating.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the Mylar Tear-Off Windshield Film (MTOWF) test program, MTOWF is appropriate for Army aircraft application. For example, the testing showed that the installation, cleaning, and removal of MTOWF was quick and easy. In addition, the optical qualities and durability of MTOWF are sufficient for Army aircraft use. Finally, testing showed that the installation of MTOWF did not degrade night vision goggle performance and that any electrostatic build-up issues could be overcome.

There are three recommendations for using MTOWF:

1. *Installation* – It is recommended that MTOWF be installed in a clean and sheltered environment. In addition to the required windscreen cleaning, the area surrounding the windscreen should be cleaned well prior to application, which will help eliminate contamination that may lead to bubbling of the MTOWF.

2. *Removal* – It is recommended the MTOWF be replaced whenever the sheet becomes difficult to see through or distracting to the pilot. It is recommended to follow the requirements described in Reference 4 and the maintenance manuals, References 1, 2, and 3, describing windscreen clarity and condition to determine when the MTOWF should be replaced.

3. *Static Charge* – It is recommended that the conductive MTOWF be adopted for aircraft usage. If the standard MTOWF is installed, it is recommended that caution be used in proximity to the film/windscreen immediately after landing, since there could potentially be a static charge present. To alleviate a static charge that might exist, the windscreen could be either wiped down with an antistatic glove or misted with water to dissipate the charge.

The ability of MTOWF to protect the windscreen, prolong its operating life, and ultimately increase aircraft readiness has been demonstrated in this test program.

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